A New Undergraduate Course on the Physics of Space Situational Awareness

Major Thomas Jost, Dr. Michael Dearborn, Dr. Francis Chun, Mr. John Clark,
Dr. Joseph Liu, Dr. Matthew McHarg, Dr. Devin Della-Rose, Dr. Roger Tippets
Department of Physics, U.S. Air Force Academy

ABSTRACT

As documented in the National Defense Authorization Act for fiscal year 2010, space situational awareness (SSA) is a high priority for the DoD and intelligence community. A fundamental understanding of the technical issues involved with SSA requires knowledge in many different scientific areas. The mission of the United States Air Force Academy (USAFA) is to educate, train, and inspire men and women to become officers of character motivated to lead the United States Air Force in service to our Nation. The physics department is implementing the USAFA mission and the need for technically competent officers in SSA through a comprehensive SSA Initiative. As part of the Initiative, we are developing a course to provide junior or senior cadets with the scientific background necessary to understand the challenges associated with SSA missions and systems. This presentation introduces the planned course objectives and includes a discussion of topics to be covered. Examples of topics include, optically resolved imaging, radiometry and photometry, radar detection and tracking, orbital prediction, debris and collision avoidance, detection of proximity operations and modeling and simulation tools. Cadets will have hands-on opportunities to collect metrics of a designated object using Academy assets such as the 41 cm telescope. Cadets will convert telescope gimbal angles into an orbital data. Cadets will synthesize what they learned in the course by completing the semester with a final project where the collected data is merged with a notional scenario to present a mock decision briefing. This class will be open to cadets of any academic major, since the intent is to prepare officers with basic technical competence in SSA applications. This is critical since graduates of the Academy become commissioned officers in the military and serve in a large variety of leadership positions – from the researcher to the warfighter. Since we are currently developing the course, the SSA community will be invited to provide feedback to USAFA physics department faculty and to participate by providing materials that may be integrated into course.

1. INTRODUCTION

The United States Air Force Academy (USAFA) (Fig. 1) in Colorado Springs, Colorado has the following mission: Educate, train, and inspire men and women to become officers of character motivated to lead the United States Air Force in service to our nation. Upon graduation, cadets receive both a Bachelor of Science degree and a commission in the United States Air Force. Cadets face a wide variety of challenges that stress teamwork through military leadership, physical training and academics. The academic requirements for all cadets involve a heavy core curriculum including two semesters of physics.

The Physics Department at USAFA, in collaboration with departments, has taken the lead to implement a Space Situational Awareness (SSA) Initiative with the goal of preparing graduates for the challenges facing today's space professionals. As seen in Fig. 2., the vision of the USAFA SSA Initiative is to replicate on a small scale, the process that the Air Force and Department of Defense (DoD) uses to exploit space for joint operations—from the use of sensors (ground and space), the flow of data into C2 centers, conversion of data into actionable information, to the development of policy and doctrine.

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14. ABSTRACT
As documented in the National Defense Authorization Act for fiscal year 2010, space situational awareness (SSA) is a high priority for the DoD and intelligence community. A fundamental understanding of the technical issues involved with SSA requires knowledge in many different scientific areas. The mission of the United States Air Force Academy (USAFA) is to educate, train, and inspire men and women to become officers of character motivated to lead the United States Air Force in service to our Nation. The physics department is implementing the USAFA mission and the need for technically competent officers in SSA through a comprehensive SSA Initiative. As part of the Initiative, we are developing a course to provide junior or senior cadets with the scientific background necessary to understand the challenges associated with SSA missions and systems. This presentation introduces the planned course objectives and includes a discussion of topics to be covered. Examples of topics include, optically resolved imaging, radiometry and photometry, radar detection and tracking, orbital prediction, debris and collision avoidance, detection of proximity operations and modeling and simulation tools. Cadets will have hands-on opportunities to collect metrics of a designated object using Academy assets such as the 41 cm telescope. Cadets will convert telescope gimbal angles into an orbital data. Cadets will synthesize what they learned in the course by completing the semester with a final project where the collected data is merged with a notional scenario to present a mock decision briefing. This class will be open to cadets of any academic major, since the intent is to prepare officers with basic technical competence in SSA applications. This is critical since graduates of the Academy become commissioned officers in the military and serve in a large variety of leadership positions ? from the researcher to the warfighter. Since we are currently developing the course, the SSA community will be invited to provide feedback to USAFA physics department faculty and to participate by providing materials that may be integrated into course.

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Fig. 1. Air Force Thunderbirds flying over the Cadet Area.

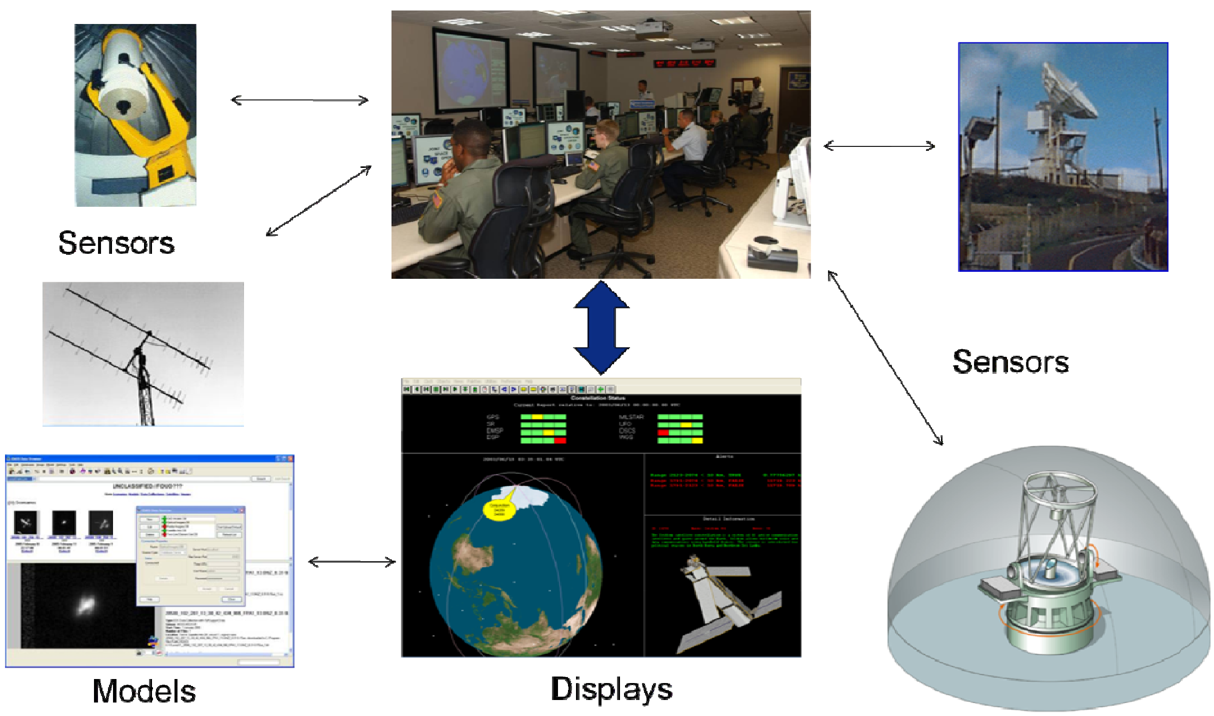


Fig. 2. USAFA SSA Initiative to replicate on a small scale, the process that the Air Force and Department of Defense (DoD) uses to exploit space for joint operations.

The SSA Initiative includes a variety of activities or thrusts such as:

- Upgrade of the current SSA capabilities of the 0.61 and 0.41 cm telescopes to enable better satellite tracking and characterization capabilities
- Acquisition of a 2m fast-tracking telescope

- Implementation of a 0.41 cm remote controlled and autonomous telescope at a separate site from USAFA to enable simultaneous collection of space object metrics from multiple sites

- Development of radar receivers to detect satellite crossings through the Air Force Space Fence and bistatic returns from other active radars off of satellites

- A Memorandum of Agreement with Air Force Space Command for mutual sharing of software tools and personnel expertise

- Optical ground characterization of FalconSAT-5 with personnel from the Air Force Research Laboratory

- Modeling and simulation research in resolvable and non-resolvable space object identification

- The inclusion of SSA sensors on board FalconSAT-5

- Implementation of a simulated Joint Space Operations Center (JSpOC)

- Development of a new undergraduate course on the physics of space situational awareness

This paper specifically discusses the new course being developed. However, we note that all of the activities listed support the teaching and content of the SSA course. The goal of this SSA course is to provide a technical foundation for future space professionals to competently address the challenges of space surveillance. Although open to all cadets who complete the second core physics course in electricity and magnetism, this course would especially be applicable to majors in physics, meteorology, basic sciences, astronautics, space operations, systems engineering, systems management, operations research, military strategic studies, and political science. The junior-level survey course will tie basic physical principles to theoretical, computational, data collection, and process applications of space surveillance and space control. Cadets successfully completing the course will comprehend the basic physics behind space surveillance technology and be able to apply that knowledge to systems and scenarios.

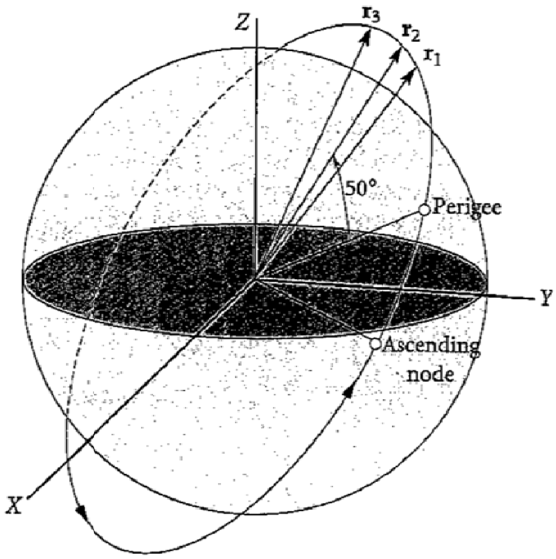
2. SSA COURSE

2.1. Course Description

The central viewpoint to the three credit course is that SSA can be viewed in terms of where a space object is and how it got there, what it is and has it changed, and do we need to worry. Topics will include space surveillance using radar and electro-optical sensors; orbit determination and prediction; high-resolution imagery; non-resolvable space object identification; and military operations in space and mission impacts. Table 1 outlines a 40-lesson syllabus for the course. Answers to these questions are crucial in deriving actionable knowledge for national defense. Students will complete lessons that are structured around this theme. To provide hands-on experience, there will be laboratories where cadets use USAFA hardware and software tools to model systems and collect data to enhance their learning.

2.2. Applied Laboratories.

In the initial orbit determination lab (Fig. 3), cadets will collect metrics using USAFA's 41 and 61 centimeter telescopes. In addition, they will be provided with existing data. They will use both provided and measured data to determine orbital parameters using methods introduced during lectures – methods such as Gibb's method (3 position vectors), Lambert's Method (2 position vectors and time) or Gauss's Method (angles only).



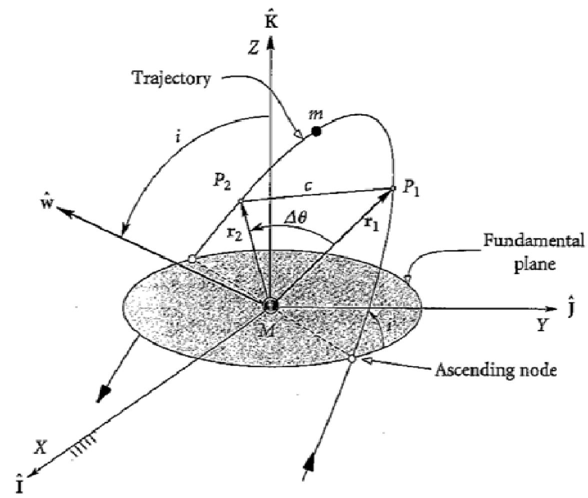


Fig. 3. Determining orbits from metric measurements.
Images taken from *Orbital Mechanics for Engineering Students*, by Howard D. Curtis [1].

In the radio frequency lab (Fig. 4), cadets will collect returns from the Air Force Space Fence using a simple radar receiver located at USAFA. Using the measurements, cadets can compare the signal strengths from different satellites and also make crude estimates of the orbital period. In addition, cadets will use the FalconSAT ground site to send a pulse train up to an amateur satellite with a communications link and intercept the returned signal to get time delay of arrival and Doppler shift information so they can compute range rate. We also intend to track satellites crossing through the Fence optically and with radar receivers to determine how much improvement can be obtained from combining the metric data.

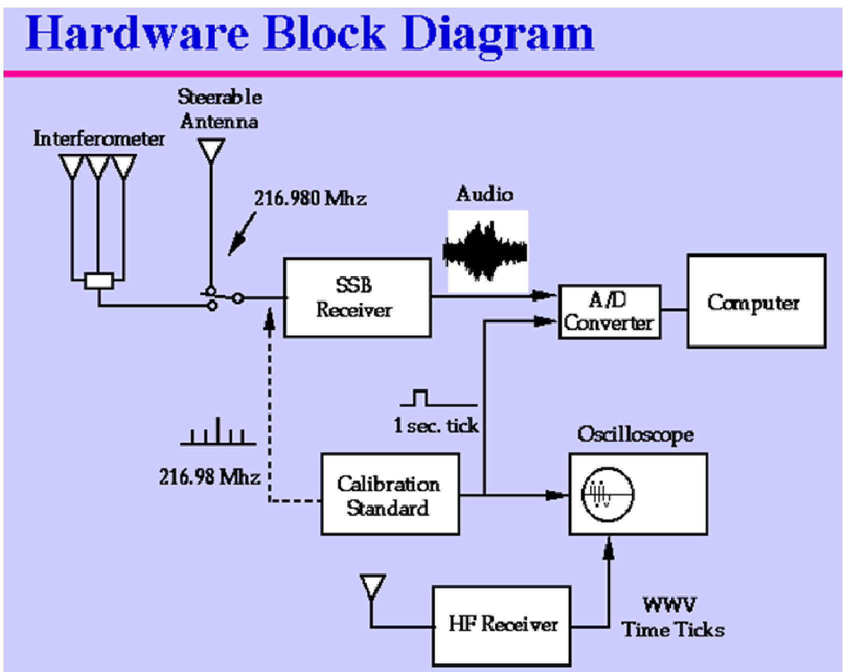


Fig. 4. Schematic of the hardware block diagram for a radar receiver [2].

In the Optical Observation Lab, cadets will perform photometry measurements of satellites using the USAFA telescopes. An example of FalconSAT-3 is shown in Fig. 5 taken from the 2.4 meter telescope at Magdalena Ridge Observatory. The Academy's current telescopes do not have the capability of tracking low earth orbiting satellites like our FalconSATs, but they can track semi-synch satellites. Fig. 6 is a series of images of a GPS satellite taken with the 41 centimeter telescope in the track mode. From the data like this, the cadets will be able to understand how to use optical systems to characterize satellites and determine their orbits. They will also be able to apply various techniques and algorithms to extract information from measurement data such as satellite shape and attitude. Ultimately, it is our hope to field small, remote and autonomous telescopes nearby the Academy with the same instrumentation in order to conduct simultaneous observations from different aspect angles on the same satellite.

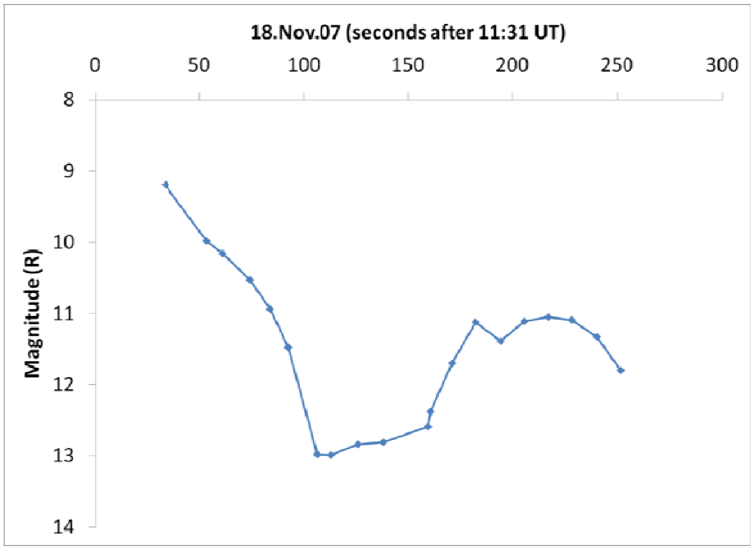


Fig. 5. Photometric light curve of FalconSAT-3. Data courtesy of Magdalena Ridge Observatory, New Mexico Institute of Technology and Mining.

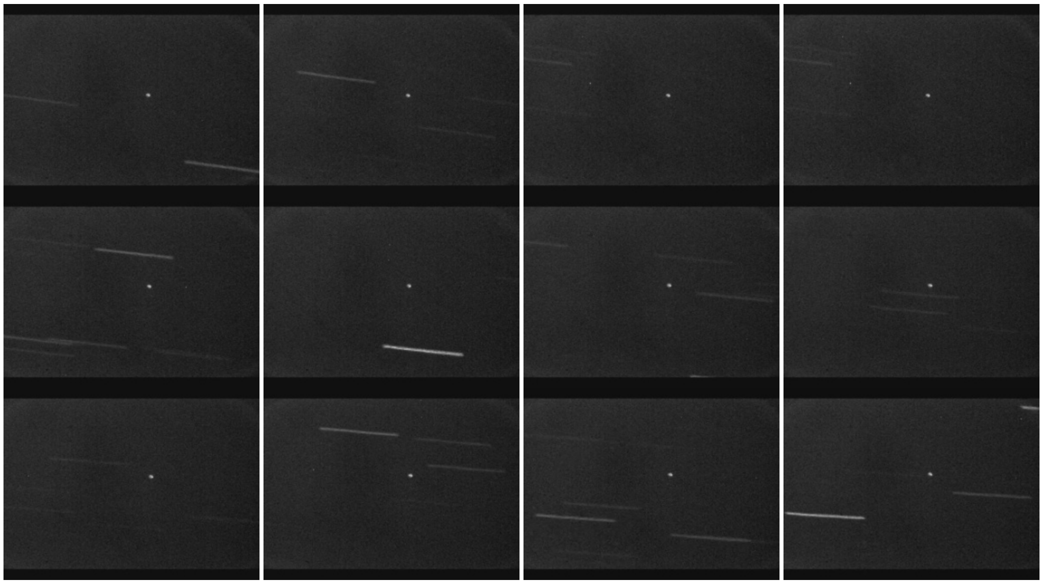


Fig. 6. Series of images (left-to-right, top-to-bottom) of a GPS satellite taken with the USAFA 41 cm telescope.

The laboratories are an invaluable opportunity for collaboration with United States SSA programs. Future space professionals will not only become aware of the assets used to collect data, but it will also solidify their understanding of the underlying physics involved in the design and use of the asset. The point of emphasis is that cadets will use USAFA hardware and compare the results to that of other SSA programs.

Table 1. Course syllabus

LESSON	TOPIC	LESSON	TOPIC
1	Administrivia, Overview of Space Situational Awareness	21	Radar Cross Section
	How it moves and where it is: Astrodynamics	22	Radar Imaging
2	Orbital Dynamics and Types of Orbits		
3	Satellite Types	23	Resolved Visible Imaging
4	Launches and Orbital Maneuvers	24	Principles of Adaptive Optics
5	Coordinate Systems and Orbital Elements	25	Photometry
6	Space Surveillance Network	26	Spectroscopy
7	Initial Orbit Determination	27	Optical Observation Lab
8	Initial Orbit Determination Project	28	Polarimetry
	How we measure where it is or how it has changed: Sensor Physics and Space Object Characterization	29	Infrared Imaging
9	Electromagnetic Spectrum	30	Graded Review #2
10	Frequency Bands and Beam Propagation		**Do we need to worry: Mission Impact**
11	Radar Fundamentals: Radar Equation	31	The Space Catalog and the Joint Space Operations Center
12	Radar Types: Monostatic, Bistatic Radars, Phased Arrays	32	Conjunction Analysis, Collisions, Debris
13	Radar Interference, Noise, and Clutter	33	Field Trip to NORAD
14	Signal Processing – Timing, Range, Doppler	34	The Space Environment and Effects
15	Radio Frequency Techniques Lab	35	Space Track; Satellite Drag and Perturbations (guest lecturer)
16	GPS and other space-based Sensors	36	Space Track; Kalman Filter
17	Graded Review #1	37	Space Track Modeling Lab
18	Optical Fundamentals; Ray and Physical, Resolution	38	Space Control; Optical and Radio Frequency Jamming
19	Charged coupled devices	39	Guest lecturer(TBD)
20	Types of Optical Telescopes: Reflecting, Refracting	40	National Security Space Policy (guest lecturer from Eisenhower Center for Space and Defense Studies)

3. CONCLUSIONS

The Department of Physics at the U.S. Air Force Academy is very interested in feedback from the SSA community of experts in several areas. First, in general, how could we improve this class in terms of scope and content? Second, because there is no text available for an undergraduate SSA course we will be assembling a collection of readings from applicable published articles. We are requesting reader participation by sharing links or copies of published readings. Credit will be cited. Third, we are interested in applicable software and tools for the modeling lab. Fourth, in order to facilitate the linkage between USAFA facilities and larger facilities throughout the Air Force and DoD, we are interested in using actual data in the classroom. Products such as images, image processing, nonresolved data and analysis, et cetera would be useful. Finally we may have some lessons available for guest lecturers. If your mission is closely tied to this course, and you can provide technical content appropriate for the undergraduate level, we may able to invite you to speak. To provide feedback or input of any kind, please e-mail Dr. Mike Dearborn at Michael.Dearborn@USAFA.edu.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

1. Curtis. H.D., “Orbital Mechanics for Engineering Students,” Elsevier Butterworth-Heinemann, pp. 201-202, 2005.

2. Kneisel, T., “Tracking satellites on a shoe-string budget,”October 1995 <http://www.k4gfg.us/navspasur/navspasur10.html>.